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Assessing Interactive Response of Humic Acid Amended Media and IBA on the Growth and Propagative Capacity of Fig (*Ficus carica* L.) Stem Cuttings

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Abstract. This study assessed the interactive effects of humic acid (HA) amended growing media (GM) and indole butyric acid (IBA) on a range of parameters determining growth and propagative capacity of Fig (*Ficus carica* L., var Black Mission) stem cuttings. Cuttings were treated varying IBA concentration (0, 500, 1000 and 1500 mg/L) and propagated in nine GM consisted of sandy loam and clay soils amended with four levels of HA (0, 2.5, 5.0, 7.5 g/m^2) and a mixture of sandy loam and clay soils (1:1 v/v) without HA. Ranking of GM changed across IBA concentrations for the majority of parameters, including plant survivability (P_S) indicated significant GM×IBA interaction. P_S increased with rising IBA concentration (500-1000 mg/L) under lower levels of HA (2.5-5.0 g/m^2) across GM. However, the relative response was better in sandy loam based GM. Based on stepwise multiple linear regression, seven parameters *viz*., percent bud sprout (P_{BS}), shoot length (S_L), shoot diameter (S_D), leaf area (L_A), leaf chlorophyll content (L_{CC}), root to shoot ratio (R/S) and plant N uptake (NUP) explained most of the variance (R^2= 99.8%) in plant survival (P_S) and acted as the critical determinants of survivability in Fig propagation *via* stem cuttings. Strong inter relationships existed among the critical traits, thus creating complex trade-offs affecting the overall propagative capacity of Fig stem cuttings. Our approach could be useful in developing indirect selection criterion determining success rates in propagation *via* stem cuttings.

Keywords: cuttings, growing media, humic acid (HA), indole butyric acid (IBA), multiple linear regression, rooting

Introduction

Vegetative propagation with stem cuttings is one of the easiest, cheapest and rapid methods for producing genetically similar nursery plants in many fruits (Hartmann *et al*., 2002). The success of propagation *via* stem cuttings is determined by several factors including the age of parent plant, type of cutting, time of sticking, physico-chemical properties of growing media (GM) (Wilson *et al*., 2003) and the strength and type of growth hormones (Mehri *et al*., 2013). However, the role of GM and growth hormones have been found to be most effective in the rooting of many plant species (Akinyele, 2010) and therefore makes the crux of this study.

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A GM having enough nutrients, moisture and proper aeration is considered suitable for cutting rooting as well as the establishment (Hartmann *et al*., 2002). In developing countries like Pakistan, nursery workers mostly use animal-based GM (*i.e*., a mix of topsoil and farm yard manure (FYM)) for plant propagation practices which is easily available, though bulky, heavy and very inconsistent in physical and chemical properties. Most animal-based substrates are low in nitrogen (N) to carbon (C) content and may harbour numerous viable weed seeds and/or pathogens such as *Salmonella* spp. or *Escherichia coli*. Besides, analysing the physical and chemical characteristics of most animal-based GM is technically demanding, costly as well as time-consuming. Thus, it is crucial to develop and/or search for clean, cheaper, stable and uniform sources of substrates as a substitute animal-based GM at least partly (Jacobs *et al*., 2009).

An alternative approach could be to supplement the soil media with humic substances (Canellas *et al*., 2015). Humic substances represent a significant source of organic carbon formed by the biochemical and microbial transformation of living matter. Humic acids (HAs) are the key constituents of humic substances comprising up to 50-80% of organic matter (Sani, 2014). The beneficial effects of HAs towards improving soil health and sustaining plant growth are well recognized (Chang *et al*., 2012; Karakurt *et al*., 2009). HAs can improve drainage as well as aeration of the GM, promote plant root system, water and nutrient uptake and establish a congenial environment for the development of beneficial micro-organisms (Canellas and Olivares, 2014). However, the HA response is dependent on plant species, mode and rate of application, source of HA, and finally, the management and environmental conditions (Trevisan *et al*., 2010a and b).

Besides GM, the root inducing capabilities of growth hormones, especially auxins are well established in propagation via stem cuttings (Pop *et al*., 2011; Went, 1934). Among the auxins, indole butyric acid (IBA) is majorly utilized for rooting induction in cuttings due to its excellent performance (Štefancic *et al*., 2007), superior stableness and weak toxicity (Hartmann *et al*., 2002). Also, the exogenous application of IBA to cuttings has been found effective in a wide range of plant species in inducing rooting on account of their higher ability to activate cambium regeneration, cell division and cell multiplication (Rymbai and Reddy, 2010).

Many studies have proved the application and advantages of HAs and auxins in the propagation of several plant species (Akinyele, 2010; Atiyeh *et al*., 2002; Fett-Neto *et al*., 2001). However, limited literature is available addressing the effectiveness and applications of HAs and auxins in the propagation of economically essential fruit species, particularly Fig (*Ficus carica* L.) *via* stem cuttings under a natural growing environment. Therefore, this study aimed to quantify and understand the interactive effects of HA amended GM and IBA on several parameters determining rooting, growth and survivability of *F. carica* stem cuttings under open field conditions. The objective was also to improve the physico-chemical characteristics of commonly available GM through the incorporation of alternative organic matter sources that are not only cheap and straightforward but sustainable as well as widely applicable, particularly in technologically underdeveloped countries.

Materials and Methods

Experiment site. The study was carried out in the research area of the Department of Horticulture, Faculty of Agriculture, Gomal University Dera Ismail Khan, Khyber Pakhtunkhwa, Pakistan. The site is located between latitude 32° 4 N′, longitude 71° 2′ and at an altitude of 173 m above sea level. The climate of the study area is arid, subtropical, and continental.

Experimental set-up. A pot experiment was performed in a factorial completely randomized design with split-plot arrangements replicated thrice. Treatments comprised of nine GM types and four IBA concentrations: 0 mg/L (control), 500 mg/L, 1000 mg/L and 1500 mg/L. Different GM consisted of sandy loam and clay soils alone and amended with three levels of HA (2.5, 5.0, 7.5 g/m^2) as well as a mixture of sandy loam and clay soils in equal proportions by volume (1:1 v/v) without HA. The GM was considered as main-plot, while IBA was treated as a sub-plot. HA source consisted of a product called "Sara" containing HA in granule form with 50% organic matter. HA was first ground into powdered form with a Wiley Mill before incorporating into the soil medium for the sake of uniformity. Respective hormone solutions were obtained by dissolving IBA at the rate of 500, 1000 and 1500 mg in one litre distilled water along with control having distilled water only. Ethyl alcohol (10 mL) was added to the solution to facilitate the dissolution process.

Freshly purchased, duly washed polyethylene bottles were turned into plastic pots (19 cm height × 8.5 cm top diameter × 8.0 cm bottom diameter) by cutting the mouth of the bottle. The resultant pot was approximately 1.5 L in volume. Four holes were made in each pot with the help of a hot iron rod for drainage purposes. Each pot was provided with a layer of potting pebbles (up to 3 cm) in the bottom to facilitate drainage and later filled up with the afore-mentioned GM. Pots were lined up in nine different plots in such a manner that each plot contained four rows of the same GM, which was treated as the main plot. Each row of six pots of the main plot was assigned to four different subplots *i.e*., IBA concentrations, respectively and replicated thrice. Thus, a total of 648 pots (9 GM × 4 IBA × 6 pots × 3 replicates) were used in this study.

Fig cuttings (23 cm length; 11 mm thick) having approximately ten dormant buds were prepared from disease-free annual shoots of a healthy mother tree (cv. Black Mission). The cuttings were dipped (Ca. 5 cm) in corresponding IBA treatments for five min and immediately cultured in the plastic pots containing pre-assigned GM under open field conditions in the first week of February 2016. Required data of air temperatures and precipitation were obtained from a weather station located near by the experimental site (Fig. 1).

All pots were managed well to avoid drought stress. After six months of culturing, GM was analysed for various chemical properties such as organic matter (OM), electrical conductivity (EC) and pH following standard methods of the Food and Agriculture Organization of the United Nations (Motsara and Roy, 2008). Data were also gathered on a broad set of parameters determining the growth, rooting, and survivability of fig cuttings. Table 1 presents the list of parameters and their measurement details.

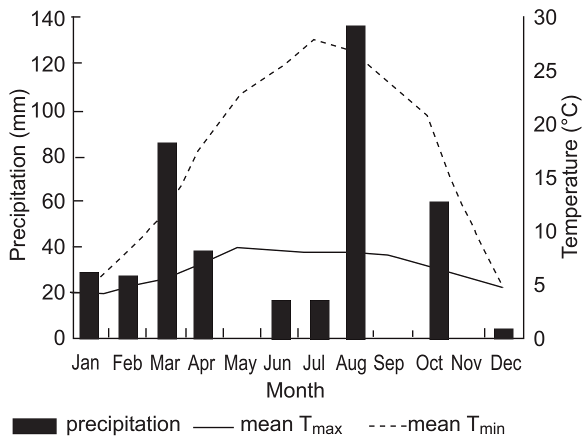

Fig. 1. Meteorological data during the experimental season (year, 2016).

Table 1. List of parameters and their methods of determination

Parameter	Acronym	Unit	Method of determination
Days taken to bud sprout	D_{BS}	%	Taken by counting the days taken to 50% sprout of cuttings after culturing in respective growing media.
Percent bud sprout	P_{BS}	%	This was calculated by dividing the number of cuttings sprouted by total number of cuttings cultured and converted to percentage.
Canopy diameter	C_D	cm	Taken by measuring plant's outer diameter with measuring tape.
Number of shoots/plant	S_N	-	Taken by counting the total of shoots initiated per plant.
Shoot length	S_L	cm	This was measured from the nodal base to shoot tip with measuring scale.
Shoot diameter	S_D	cm	Quantified by measuring the thickness of new shoots with Vernier Caliper and calculating their average.
Number of leaves/plant	L_N	-	Taken by physically counting the number of leaves appeared per plant.
Leaf area	L_A	cm^2	L_A was quantified as: $L_A = 0.90(L_L \times L_W)$; where L_L and L_W represent maximum lamina length and width, respectively.
Leaf chlorophyll content	L_{CC}	-	This was measured through SPAD-502 meter.
Number of roots/cutting	R_N	-	Taken by counting the total number of roots appeared per cutting.
Root length	R_L	cm	Taken with the help of measuring tape for all the appeared roots per cutting and average was made.
Root diameter	R_D	cm	Taken by measuring the thickness of roots with Vernier Caliper and calculating their average.
Plant dry matter content	P_{DMC}	%	This was calculated by dividing the dry weight of plant by fresh weight of plant and converted to percentage.
Root to shoot ratio	R/S	-	This was calculated by dividing the dry weight of roots by dry weight of shoots per cutting.
Plant N uptake	NUP	mg/plant	Total amount of N in the plant was calculated from the N concentration (N_C) and plant dry weight. N_C was estimated following AOAC (2016).
Plant survival	P_S	%	Taken by dividing the number of plants survived by total number of cuttings sprouted and converted to percentage.

Statistical analyses. The significance of variation due to GM, IBA and their interaction (GM × IBA) on a broad set of parameters were assessed by performing general analysis of variance and means were separated through LSD (Least Significant Difference) test. Multiple linear regression (stepwise) was performed for percent plant survival (P_S) as a response variable and the rest of the parameters as predictor variables in order to find critical parameters explaining most variance in P_S. Pearson correlations coefficients were estimated to assess inter-relationships among the key parameters identified. Genstat (Payne *et al*., 2009) statistical package was used to perform all the statistical procedures.

Results and Discussion

Assessing chemical properties of growing media (GM). The addition of HA positively improved the nutrient status of both sandy loam and clay-based GM compared with control (without HA) (Arjumend *et al*., 2015). The extent of improvement in chemical properties was great in HA amended clay GM followed by sandy loam GM as evident from higher mean values of OM and EC in clay-based GM (Table 2). However, the relative increase in chemical properties of GM amended with HA was much higher in sandy loam than clay-based media over GM without HA application. The relative increase in OM and EC in sandy loam based GM amended with HA (2.5, 5.0 and 7.5 g HA/m^2) was in the range of 48.6, 77.1, 117.1 and 95.3, 119.0, 125.7%, respectively over sandy loam soil alone. Compared with clay soil alone, the addition of HA at the rates of 2.5, 5.0, and 7.5 g HA/m^2 improved the nutrient status by increasing OM (24.0, 50.0, 93.0%) and EC (18.3, 49.9, 64.8%), respectively. Results further indicated an increase in OM (97.1%) and EC (176.3%) in GM having a mixture of sandy loam and clay soil (1:1 v/v) over sandy loam GM alone. On the other hand, the same media indicated a decrease in OM (-31.0%) and an increase in EC (25.5%) over clay GM alone. Furthermore, results indicated that the change in pH across various GM was conservative, with mean values ranging from 7.38 to 7.64 (Table 2), which might be due to the buffering effect of HA that resisted a significant change in pH (Boguta and Sokotowska, 2012; Tahir *et al*., 2011). Soils with high amounts of clay and/or OM typically have higher EC values and cation exchange capacity (Nigussie *et al*., 2012). Overall, it was concluded that the addition of HA could help overcome the nutrient limitation of certain media (Becher, 2013).

Table 2. Chemical properties of different growing media (GM)

GM	Soil type	†HA (g/m^2)	Organic matter (%)	EC (dS/m)	pH
M1	Sandy loam	-	0.35	0.253	7.40
M2	Sandy loam	2.5	0.52	0.494	7.64
M3	Sandy loam	5.0	0.62	0.554	7.61
M4	Sandy loam	7.5	0.76	0.571	7.49
M5	Clay	-	1.00	0.557	7.44
M6	Clay	2.5	1.24	0.659	7.47
M7	Clay	5.0	1.50	0.835	7.48
M8	Clay	7.5	1.93	0.918	7.38
M9	Sandy loam + Clay*	-	0.69	0.699	7.55

* equal proportions = (1:1 v/v); † = amendment with humic acid.

Assessing the response of GM on growth, rooting, and survivability of Fig cuttings. Environments created by different GM had a highly significant ($P < 0.001$) effect on all the examined parameters (data not shown). D_{BS} increased with the rise in HA availability until 5.0 g/m in both sandy loam and clay-based GM (Table 3). Minimum D_{BS} (43.83) was achieved in sandy loam GM without HA amendment, whereas maximum D_{BS} (57.96) was recorded in clay amended with 5.0 g HA/m^2. P_{BS} increased with the rise in HA application till 7.5 g/m^2 in both sandy loam and clay-based GM (Table 3). However, P_{BS} values were comparatively lower in clay-based GM. Maximum P_{BS} (92.29%) was noted in sandy loam amended with 7.5 g HA/m^2. On the contrary, the absence of HA reduced P_{BS} to 61.75% and 31.29% in both sandy loam and clay-based GM, respectively. C_D, S_N and S_L: declined with the incremental rise in HA application (5.0-7.5 g/m^2) in both GM (sandy loam and clay). Maximum ‘‘C_D, S_N, and S_L’’ (26.14 cm, 5.38 and 5.43 cm, respectively) were observed in sandy loam applied with 2.5 g HA/m^2. On the other hand, all these parameters attained minimum values (*i.e.*, 13.53, 2.28 and 3.08 cm, respectively) in clay GM without HA application (Table 3). S_D increased with the application of HA (2.5-7.5 g/m^2) in both GM (sandy loam and clay). However, S_D was maximum (0.491 cm) in clay amended with 7.5 g HA/m^2 and minimum (0.289 cm) in sandy loam GM alone (Table 3). L_N and L_A showed an increasing trend with the increase in HA levels (2.5-5.0 g/m^2) and their maximum values (10.07 and 114.04 cm^2, respectively) were noted in sandy loam GM amended with 5.0 g HA/m^2 (Table 3). On the other hand, minimum L_N (3.81) and L_A (56.48 cm^2) were recorded in clay-based GM without HA addition. As expected, L_{CC} increased with the rise in HA supply (2.5-7.5 g/m^2) in both GM (sandy loam and clay) (Table 3). The GM with high HA availability (7.5 g/m^2) exhibited maximum L_{CC} (42.19) in sandy loam GM followed by L_{CC} (41.21) in clay-based GM. L_{CC} was lowest (23.7 and 32.51) in both sandy loam and clay-based GM, respectively, without HA application (Table 3). Maximum R_N and R_D (124.81, 0.22 cm, respectively) were produced at 7.5 g HA/m^2 in sandy loam and clay-based GM, respectively (Table 3). Minimum R_N (58.95) and R_D (0.130 cm) were recorded in clay GM without the HA application. Opposingly, R_L decreased with an increase in HA application (2.5-7.5 g/m^2) in both sandy loam and clay-based GM (Table 3). The clay-based GM produced maximum R_L (14.22 cm) followed by sandy loam GM (12.93 cm) without the HA application. Minimum R_L (10.4 cm) was observed in sandy loam GM followed by 11.2 cm RL in clay-based GM amended with the maximum level of HA (7.5 g/m^2). P_{DMC} and R/S increased gradually with rising HA availability (2.5-7.5 g/m^2) irrespective of GM type (Table 3). However, the mean values of P_{DMC} and R/S were higher in clay-based GM than sandy loam GM. Cuttings produced maximum P_{DMC} (46.00%) and R/S (0.665) in the clay-based GM with the highest HA availability (*i.e.*, 7.5 g/m^2). Minimum P_{DMC} (34.26%) and R/S (0.308) were produced in sandy loam GM without the HA application. The results further indicated a differential response of NUP to HA availability across sandy loam and clay-based GM. This was indicated by an increasing trend in NUP with rising HA availability (2.5-7.5 g/m^2) in sandy loam GM (Table 3). On the other hand, in the case of clay-based GM, NUP first indicated increasing trend at 2.5 g HA/ m and later decreased with further application of HA (5.0-7.5 g/m^2). Overall, maximum

Table 3. Effects of growing media (GM) on different parameters of Fig

RM	D_{BS}	P_{BS} (%)	C_D (cm)	S_N	S_L (cm)	S_D (cm)	L_N	L_A (cm^2)	L_{CC}
M1	43.83 i	61.75 g	24.9 b	4.41 d	4.66 d	0.289 i	7.47 e	84.14 d	23.70 i
M2	47.71 f	79.61 e	26.14 a	5.38 a	5.43 a	0.334 h	9.77 b	104.82 b	25.48 h
M3	48.22 e	91.45 b	24.51 c	4.91 b	5.13 b	0.357 f	10.07 a	114.04 a	30.04 g
M4	46.87 h	92.29 a	21.49 e	3.83 e	4.56 e	0.392 d	8.43 d	99.45 c	42.19 a
M5	48.93 d	31.29 i	13.53 i	2.28 i	3.08 i	0.351 g	3.81 i	56.48 h	32.51 f
M6	54.46 b	53.29 h	16.21 f	3.23 f	3.81 f	0.403 c	5.53 g	72.82 e	37.24 e
M7	57.96 a	71.06 f	15.89 g	3.15 g	3.60 g	0.444 b	5.66 f	71.02 f	39.39 d
M8	50.04 c	84.68 d	14.45 h	2.78 h	3.35 h	0.491 a	5.21 h	66.89 g	41.21 b
M9	47.56 g	90.47 c	23.10 d	4.51 c	4.87 c	0.374 e	9.33 c	105.48 b	40.19 c
LSD	0.079	0.421	0.233	0.057	0.050	0.003	0.101	0.994	0.303

	R_N	R_L (cm)	R_D (cm)	P_{DMC} (%)	R/S	NUP	P_S (%) (mg/plant)
M1	75.30 f	12.93 b	0.147 h	34.26 i	0.308 i	23.00 e	62.93 f
M2	102.30 d	12.48 d	0.172 f	36.37 g	0.352 h	26.00 d	82.47 c
M3	119.01 c	11.57 f	0.197 c	38.50 f	0.369 g	29.00 c	87.55 a
M4	124.81 a	10.4 h	0.220 a	41.08 c	0.437 e	34.00 a	79.94 d
M5	58.95 i	14.22 a	0.130 i	34.97 h	0.464 d	20.38 g	43.06 i
M6	64.85 h	12.82 c	0.153 g	38.88 e	0.553 c	22.51 f	57.10 g
M7	67.74 g	12.03 e	0.175 e	42.72 b	0.593 b	20.39 g	66.16 e
M8	77.43 e	11.20 g	0.180 d	46.00 a	0.665 a	13.93 h	51.23 h
M9	121.57 b	11.13 g	0.205 b	39.69 d	0.398 f	31.09 b	86.28 b
LSD	1.199	0.106	0.004	0.329	0.003	0.163	0.237

Means separated by different letters are significant at $P < 0.05$. For the acronyms of parameters, see Table 1. M1 = sandy loam soil alone; M2 = sandy loam soil + 2.5 g HA/m^2; M3 = sandy loam soil + 5.0 g HA/m^2; M4 = sandy loam soil + 7.5 g HA/m^2; M5 = clay soil alone; M6 = clay soil + 2.5 g HA/m^2; M7 = clay soil + 5.0 g HA/m^2; M8 = clay soil + 7.5 g HA/m^2; M9 = sandy loam soil + clay soil (1:1 v/v).

N_{UP} (34.0 mg/plant) was exhibited by sandy loam GM amended with 7.5 g HA/m^2 followed by 31.09 mg/plant NUP in a mixture of sandy loam and clay soil (1:1 v/v). The absence of HA in both GM (sandy loam and clay soil) induced the lowest N_{UP} (23.00, 20.38 mg/plant, respectively). P_S increased positively with the incremental rise in HA availability until 5.0 g/m, where the maximum P_S (87.55% and 66.16%) was recorded in sandy loam and clay-based GM, respectively (Table 3). Overall, mean P_S was higher in sandy loam GM than clay-based GM, irrespective of HA application. Further comparison of two GM indicated that the absence of HA application resulted in minimum P_S (43.06% and 62.93%) in clay and sandy loam GM, respectively.

Our results indicated that the amendment of GM with HA had a positive impact on bud sprout, leaf formation, and canopy growth and development (Sharif *et al*., 2002). Studies have shown that HA input to the GM may result in enhanced photosynthesis, protein synthesis, and enzymatic activities in plants, which might be linked to higher L_{CC} (Ulukan, 2008). HA had a dominating effect on root development compared to the shoot (Fahramand *et al*., 2014) that might have resulted in high values of R/S and subsequently P_{DMC} with the rise in HA availability in both sandy loam and clay-based GM (Eyheraguibel *et al*., 2008). High NUP with more HA availability in sandy loam GM can be attributed to stimulation of maximum nutrient uptake by the plant as it promotes the conversion of mineral nutrients into forms available to plants (Abbas *et al*., 2013). On the other hand, decreasing trends for NUP in clay-based GM could be due to relatively lesser above ground develop-ment or, in other words, more R/S, thereby creating a limited driving force for N_{UP} which resulted in lower P_S values in clay-based GM. Results further indicated that GM could be ranked based on maximum P_S as sandy loam > sandy loam + clay > clay. Overall, results concluded that sandy loam GM amended with HA (5.0-7.5 g/m^2) was most effective on account of their beneficial effects on the majority of the parameters, whereas clay GM alone was least useful for the propagation of Fig *via* stem cuttings.

Assessing the response of IBA on growth, rooting, and survivability of Fig cuttings. IBA had a highly significant ($P < 0.001$) effect on all the parameters determining the rooting, growth and survivability of Fig cuttings (data not shown). Results indicated a linear decrease in D_{BS} with the rise in IBA concentration (500-1500 mg/L) (Table 4). Minimum D_{BS} (43.83) was noted at 1500 mg IBA/L, whereas control (0 mg IBA/L) took maximum D_{BS} (55.89). P_{BS} increased with rising IBA concentration and maximum value (88.26%) was obtained from 1000 mg IBA/L (Table 4). P_{BS} was lowest in control (0 mg IBA/L). Results indicated extension in C_D, S_N, L_N, L_A, R_N, R_D and N_{UP} with rising IBA concentration (500-1000 mg/L), with their maximum values (23.69 cm, 4.97, 8.57, 100.69 cm^2, 106.99, 0.230 cm and 31.84 mg/plant, respectively) recorded at 1000 mg IBA/L (Table 4). Data also revealed that the absence of IBA application (*i.e*., control) resulted in the lowest C_D (15.57 cm), S_N (2.67), L_N (5.62), L_A (62.29 cm^2), R_N (65.13), R_D (0.086 cm) and NUP (16.86 mg/plant). It

Table 4. Effects of indole butyric acid (IBA) on different parameters of Fig

IBA (mg/L)	D_{BS}	P_{BS} (%)	C_D (cm)	S_N	S_L (cm)	S_D (cm)	L_N	L_A (cm^2)	L_{CC}
0	55.89 a	48.69 d	15.57 d	2.671 d	3.05 d	0.393 c	5.62 d	62.29 d	37.68 a
500	51.26 b	76.28 c	22.19 b	4.624 b	3.87 c	0.426 a	7.84 b	86.08 c	36.50 b
1000	47.05 c	88.26 a	23.69 a	4.974 a	4.64 b	0.397 b	8.57 a	100.69 a	34.70 c
1500	43.83 d	78.28 b	18.65 c	3.072 c	5.55 a	0.311 d	6.98 c	95.45 b	30.06 d
LSD	0.053	0.280	0.155	0.038	0.034	0.001	0.067	0.663	0.280

IBA (mg/L)	R_N	R_L (cm)	R_D (cm)	P_{DMC} (%)	R/S	NUP (mg/plant)	P_S (%)
0	65.13 d	15.68 a	0.086 d	46.94 a	0.531 a	16.86 d	50.62 d
500	92.93 c	12.10 b	0.182 c	42.25 b	0.456 b	18.84 c	72.00 b
1000	106.99 a	10.53 c	0.230 a	39.09 c	0.435 c	31.84 a	79.97 a
1500	95.82 b	10.03 d	0.206 b	28.38 d	0.418 d	30.36 b	71.52 c
LSD	0.799	0.07	0.001	0.219	0.006	0.109	0.158

Means separated by different letters are significant at $P < 0.05$. For the acronyms of parameters, see Table 1.

was interesting to note that S_L increased with the incremental rise in IBA concentration (500-1500 mg/L), whereas an opposite trend was observed for S_D, which decreased with the high IBA concentration. This was also evident from higher S_L (5.55 cm) and lower S_D (0.311 cm) recorded at 1500 mg IBA/L (Table 4). L_{CC}, R_L, P_{DMC} and R/S showed a decreasing trend with an increase in IBA concentration (500-1500 mg/L) (Table 4). As a result, maximum values of L_{CC} (37.68), R_L (15.68 cm), P_{DMC} (46.94%) and R/S (0.531) were observed from control (0 mg/IBA/L). Treatment with highest IBA concentration (1500 mg/L) produced least L_{CC} (30.06), R_L (10.03 cm), P_{DMC} (28.38%) and R/S (0.418).

P_S ranged from 50.62% to 79.97% (Table 4). P_S was higher with rising IBA concentration (500-1000 mg/L), with maximum P_S (79.97%) noted at 1000 mg IBA/L. Further application of IBA (1500 mg/L) resulted in reduced P_S. Overall, P_S was lowest (50.62%) in control (0 mg IBA/L). Results concluded that better development of the root and shoot parameters at 1000 mg IBA/L resulted in better P_S. Our conclusion was supported by Ahmad *et al*. (2002) in bougainvillea, Shukla *et al*. (2010) in peach, Diwaker and Katiyar (2013) in lime, Kaur *et al*. (2016) in pomegranate.

Assessing the interactive response of GM and IBA (GM×IBA) on growth, rooting, and survivability of Fig cuttings. The impact of GM×IBA interaction was highly significant ($P < 0.001$) in all the parameters studied (data not shown). The relationships between IBA and environments created with different GM were strongly expressed with R^2 values > 97% (Fig. 2-3). Results revealed a decrease in D_{BS} with an increase in IBA concentrations (500-1500 mg/L) across the entire GM (Fig. 2). Overall, the combination of IBA (1500 mg/L) with sandy loam GM alone produced the lowest D_{BS} (36.7). The interaction between control (0 mg IBA/L) and clay GM amended with 5.0 g HA/m^2 produced the highest D_{BS} (71.3). P_{BS} increased with the rise in IBA and HA availability until 1000 mg/L and 7.5 g/m^2, respectively, in the majority of the GM (Fig. 2). Overall, clay-based GM exhibited lower P_{BS} across the IBA concentrations, with only 10% P_{BS} observed at (0 mg/ IBA/L) under clay GM alone. C_D, S_N, L_N, and L_A increased with rising IBA concentrations (500-1000 mg/L), however, in the presence of lower levels of HA across most of the GM (Fig. 2). IBA (1000 mg/L) and sandy loam GM amended with 2.5 g HA/m^2 produced maximum C_D (29.0 cm) and S_N (6.5) whereas, the same IBA concentration produced maximum L_N and L_A (11.60, 126.0 cm^2, respectively) under sandy loam GM amended with 5.0 g HA/m^2. Overall, the minimum values of these parameters were recorded in cutting treated with 0 mg IBA/L (control) followed by 1500 mg IBA/L under clay-based GM. Almost similar trends were observed for R_N, R_D, P_{DMC} and NUP regarding IBA concentration (1000 mg/L) with the exception that values of these parameters increased with the rise in HA application (2.5-7.5 g/m^2) irrespective of GM type (Fig. 3). It was further noted that IBA (1000 mg/L) produced maximum values of R_N and R_D (131.9, 0.280 cm, respectively) under sandy loam GM and P_{DMC} (55.0%) under clay GM amended with 7.5 g HA/m^2. On the other hand, the combination of clay GM alone in the absence of IBA (*i.e*., control) produced minimum R_N (38.0), R_D (0.020 cm) and P_{DMC} (20.8%). S_L was high in sandy loam GM than clay-based GM and indicated an increasing trend with increasing concentration of IBA (500-1500 mg/L) under low application of HA (2.5 g/m) (Fig. 2). As a result, the combination of 1500 mg/ IBA/L and sandy loam GM amended with 2.5 g HA/m^2 produced maximum S_L (6.6 cm) as compared to lowest S_L (2.4 cm) with 0 mg IBA/L (control) under clay GM alone. S_D, on the other hand, was high in clay-based GM than sandy loam GM, where maximum S_D (0.540 cm) was noted with 500 mg IBA/L under clay GM amended with 5.0 g HA/m^2 (Fig. 2). L_{CC} increased with the incremental rise in IBA concentration (500-1000 mg/L) throughout the GM with maximum L_{CC} (44.0) recorded at 1000 mg IBA/L under sandy loam GM amended with 7.5 g HA/m^2 (Fig. 3). R_L decreased with an increase in the strength of IBA (500-1500 mg/L) and H_A (2.5-7.5 g/m^2) irrespective of GM type (Fig. 3). However, mean R_L was comparatively higher in clay-based GM. The interaction of IBA (0 mg/L) and clay GM alone produced maximum R_L (20.0 cm). Minimum R_L (8.57 cm) was recorded in cuttings treated with IBA (1500 mg/L) under sandy loam GM amended with 7.5 g HA/m^2. R/S indicated almost similar trends concerning IBA concentration and GM type, with the exception that R/S increased with an incremental boost in HA availability (2.5-7.5 g/m^2) (Fig. 3). The combination of 0 mg IBA/L (control) and clay GM treated with 7.5 g HA/m^2 exhibited maximum R/S (0.710 cm). On the contrary, R/S was minimum (0.290 cm) in cuttings applied with 1500 mg IBA/L under sandy loam GM alone.

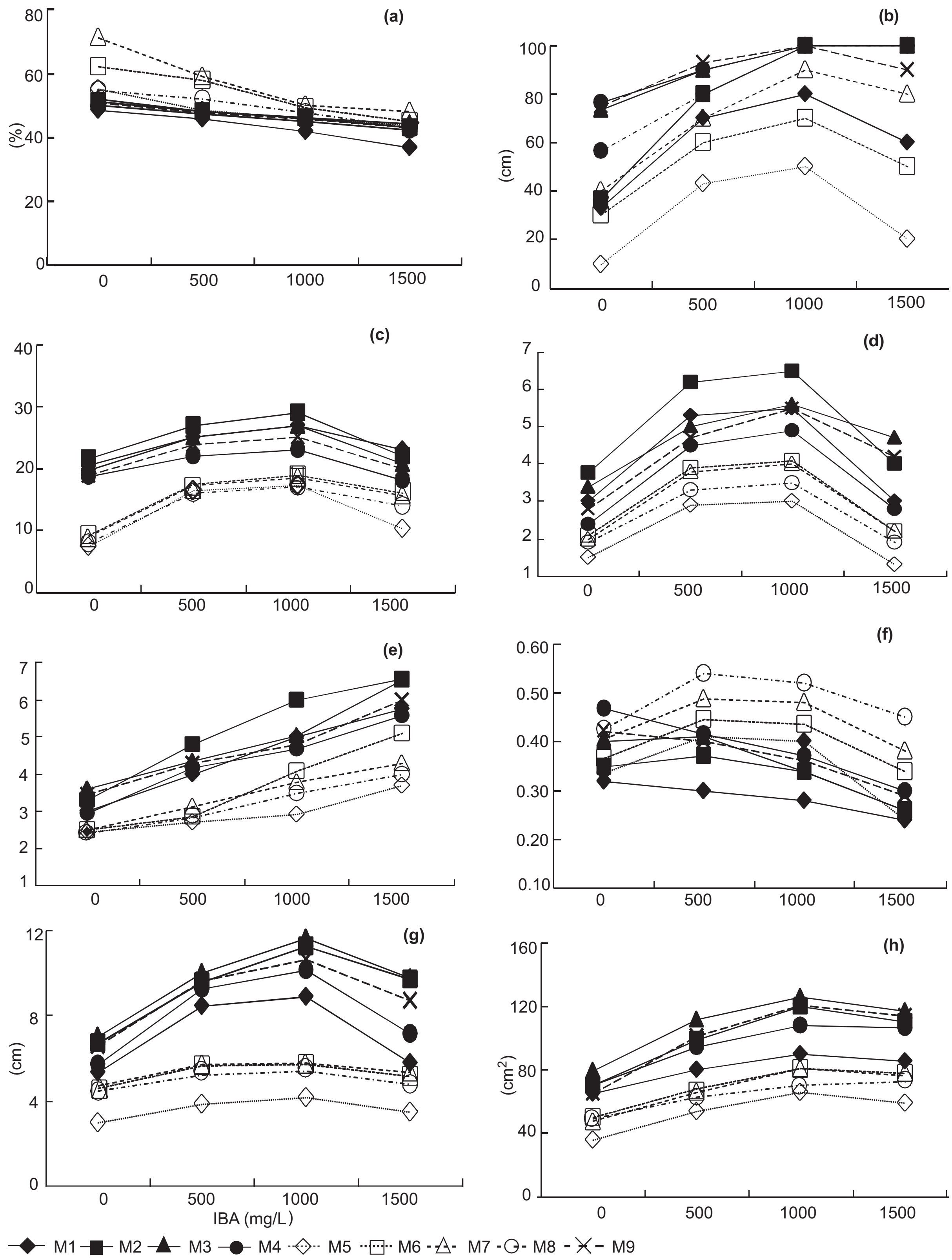

Fig. 2. Effect of GM×IBA interaction on different parameters of Fig. **(a)** D_{BS}, **(b)** P_{BS}, **(c)** C_D, **(d)** S_N, **(e)** S_L, **(f)** S_D, **(g)** L_N, **(h)** L_A. For acronyms and units of parameters, see Table 1. For the acronyms of GM, see Table 2.

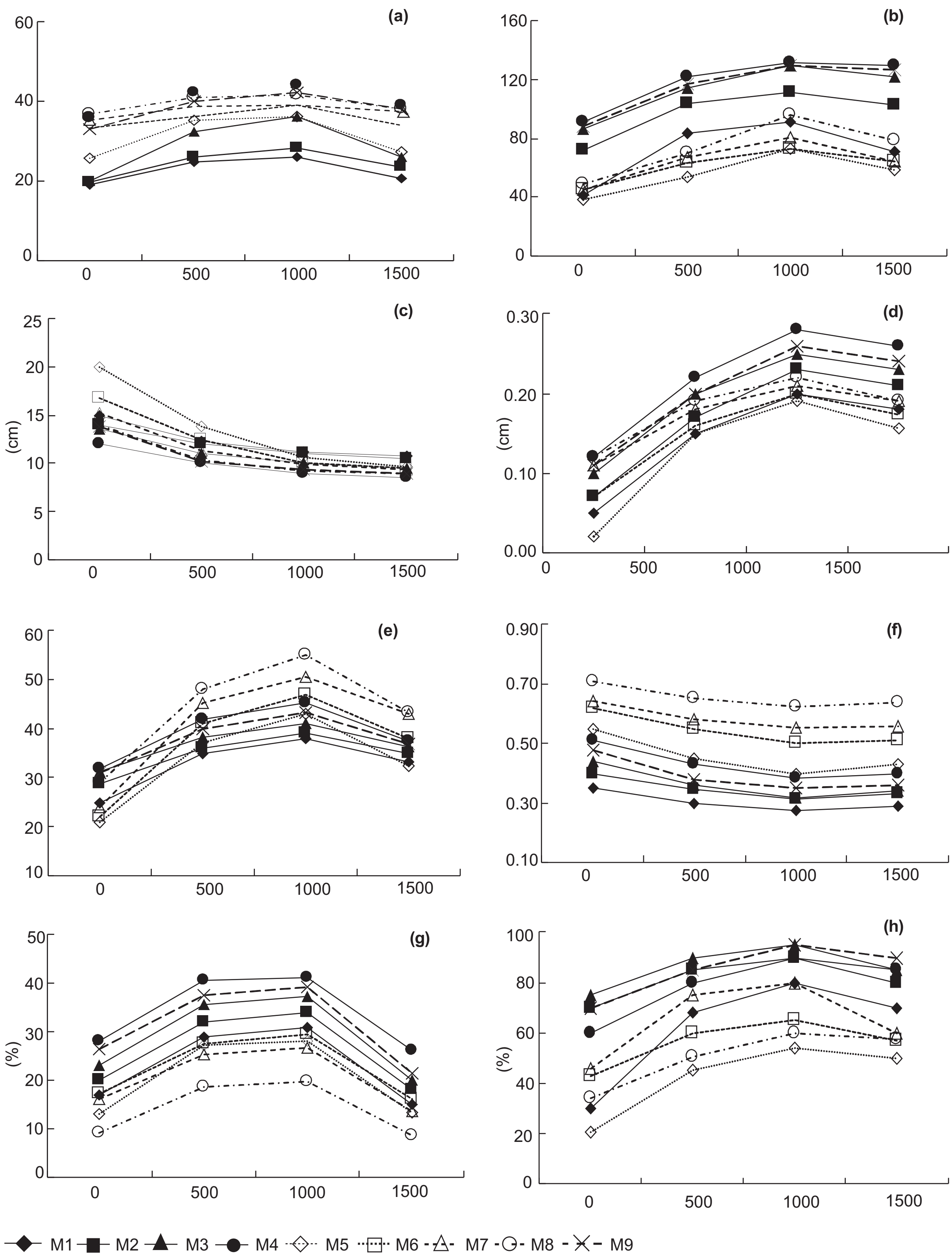

Fig. 3. Effect of GM×IBA interaction on different parameters of Fig cuttings. **(a)** L_{CC}, **(b)** R_N, **(c)** R_L, **(d)** R_D **(e)** P_{DMC}, **(f)** R/S, **(g)** NUP, **(h)** P_S. For the acronyms and units of parameters, see Table 1. For the acronyms of GM, see Table 2.

P_S increased with rising IBA concentration (500-1000 mg/L) and under lower levels of HA (2.5-5.0 g/m^2) in both the GM (sandy loam and clay) (Fig. 3). However, the relative response was better in sandy loam based GM. Maximum P_S (95.0%) was obtained in cuttings treated with 1000 mg IBA/L under sandy loam GM applied with 5.0 g HA/m^2 (Fig. 3). Similar results were also obtained when cutting cultured in a mixture of sandy loam and clay GM (1:1). P_S was lowest (20.7%) in control (0 mg IBA/L) and clay GM alone. Similar trends were observed in pomegranate (Ram *et al*., 2005), Fig (Reddy *et al*., 2008), lime (Diwaker and Katiyar, 2013) and peach (Shukla *et al*., 2010).

Further investigation of the data indicated that the ranking of some GM changed across different IBA concentrations for the majority of parameters including P_{BS}, C_D, S_N, S_L, S_D, L_N, L_A, R_N, P_{DMC}, NUP and P_S. These results concluded that the responsiveness of IBA application on rooting, growth, and survivability of Fig cuttings depends upon the physical and chemical properties of GM (Raviv, 2011).

Identification of key parameters determining plant survivability in Fig. In this section, we aimed to develop an approach for identifying critical parameters among the broad set of parameters having a more significant influence on the survivability of Fig stem cuttings. This could help in devising an alternative approach for increasing the overall success rate in Fig propagation *via* stem cuttings. A stepwise multiple linear regression procedure was followed using a forward selection approach, where each independent parameter (predictor variable) was introduced into the regression model sequentially one at a time based on increasing variance (R^2) explained by the model for the dependent variable (*i.e*., P_S).

Total of sixteen models were tested based on the principles elaborated earlier. Among these, model No. 5, No. 6 and No. 7 explained most of the variance (94.1, 98.3, and 99.8%, respectively) in P_S (Table 5). In model No. 5, five parameters (P_{BS}, S_L, S_D, L_A and L_{CC}), in model No. 6, six parameters (P_{BS}, S_L, S_D, L_A, L_{CC}, R/S), while in model No. 7, seven parameters (P_{BS}, S_L, S_D, L_A, L_{CC}, R/S, and NUP) had a highly significant ($P < 0.001$) combined effect on PS among a large set of parameters.

We found that growth attributes such as P_{BS}, S_L, S_D, L_A, L_{CC}, R/S and NUP are the critical determinants of survivability in Fig propagation via stem cuttings. This was supported by a close relationship (1:1) between predicted versus observed P_S (data not shown). Overall,

Table 5. Stepwise regression analysis of different parameters using plant survival (P_S) as a dependent variable

Set of parameters[a]	Model no. 1	Model no. 2	Model no. 3	Model no. 4	Model no. 5	Model no. 6	Model no. 7
D_{BS}	-	-	-	-	-	-	-
P_{BS}	+	+	+	+	+	+	+
C_D	-	-	-	-	-	-	-
S_N	-	-	-	-	-	-	-
S_L	-	+	+	+	+	+	+
S_D	-	-	+	+	+	+	+
L_N	-	-	-	-	-	-	-
L_A	-	-	-	+	+	+	+
L_{CC}	-	-	-	-	+	+	+
R_N	-	-	-	-	-	-	-
R_L	-	-	-	-	-	-	-
R_D	-	-	-	-	-	-	-
P_{DMC}	-	-	-	-	-	-	-
R/S	-	-	-	-	-	+	+
NUP	-	-	-	-	-	-	+
R2***	20.9	89.2	91.7	92.5	94.1	98.3	99.8

For the acronyms and units of parameters, see Table 1. a '+' = indicates the independent parameter whose mean value was included in the regression model; '-' = symbol indicates the independent trait whose mean value was not included in the regression model; b = Percentage of variation explained in plant survival (P_S) by the model; *** = Significant at $P < 0.001$.

results revealed that a positive response of GM (mainly sandy loam) amended with HA (2.5-5.0 g/m^2) and IBA (1000 mg/L) on the rooting, growth, and survivability of Fig cuttings is driven mainly by our selected parameters. Our results were supported by Singh and Singh (2005, 2000) and Siddiqui and Hussain (2002).

Assessing correlations among the key parameters determining plant survivability in Fig. Results indicated significant ($P < 0.001$) inter-relationships among the key parameters determining plant survivability in Fig (Table 6). There were very strong positive ($r \geq 0.70$) correlations between S_L and L_A (r = 0.88), between R/S and S_D (r = 0.85), between NUP and L_A (r = 0.81), S_L (r = 0.72), between L_A and PBS (r = 0.75). The results further indicated moderately strong posi-tive correlations ($0.40 \leq r < 0.70$) between L_{CC} and R/S (r = 0.54); between NUP and P_{BS} (r = 0.48), between S_L and P_{BS} (r = 0.43).

The results also showed very strong negative correlations ($r \geq -0.70$) between S_D and S_L (r = -0.93), L_A ($r \geq -0.79$), NUP (r = -0.75), between R/S and S_L (r = -0.90). There were moderately strong negative correlations ($-0.40 \leq r \leq -0.70$) between R/S and L_A (r = -0.67), between L_{CC} and S_L (r = -0.54), L_A (r = -0.40), between NUP and R/S (r = -0.63).

Data further indicated very strong positive correlations between P_S and most of the parameters including S_L, L_A and NUP (r = 0.78 to 0.95) (Table 6). There were moderately strong positive correlations between P_S and P_{BS} (r = 0.41). There were very strong negative correlations between P_S and S_D (r = -0.95), R/S (r = -0.89). Data also revealed moderately strong negative correlations between P_S and L_{CC} (r = -0.55). These results revealed the presence of strong inter-relationships among the key traits determining the overall propagative capacity of Fig stem cuttings.

Table 6. Correlation coefficients among critical parameters of Fig

	P_{BS}	S_L	S_D	L_A	L_{CC}	R/S	NUP	P_S
P_{BS}	-	-	-	-	-	-	-	-
S_L	0.43	-	-	-	-	-	-	-
S_D	-0.25	-0.93	-	-	-	-	-	-
L_A	0.75	0.88	-0.79	-	-	-	-	-
L_{CC}	-0.22	-0.54	0.34	-0.40	-	-	-	-
R/S	-0.13	-0.90	0.85	-0.67	0.54	-	-	-
NUP	0.48	0.72	-0.75	0.81	0.11	-0.63	-	-
P_S	0.41	0.95	-0.95	0.86	-0.55	-0.89	0.78	-

For the acronyms and units of parameters, see Table 1.

Conclusion

Overall, this study concluded that sandy loam GM amended with HA (5.0-7.5 g/m^2) was most effective on account of their beneficial effects on the majority of the traits determining growth, rooting and survivability of Fig cuttings. In contrast, clay GM alone was least effective for the propagation of Fig *via* cuttings. GM was ranked based on effectiveness as sandy loam>sandy loam + clay>clay. IBA (1000 mg/L) was superior in terms of inducing positive effects on the majority of the parameters over control (0 mg IBA/L). The interactive response of GM × IBA indicated higher plant survival with IBA concentrations ranging from 500-1000 mg/L and under lower levels of HA (2.5-5.0 g/m^2) in both the GM (sandy loam and clay). However, the relative response was better in sandy loam-based GM. Plant survival was lowest in control (0 mg IBA/L) and clay GM alone. Results concluded that the responsiveness of IBA application on Fig cuttings depends upon the physical and chemical properties of GM. Results of stepwise multiple linear regression analysis concluded that growth attributes such as percent bud sprout, shoot length, shoot diameter, leaf area, leaf chlorophyll content, root to shoot ratio, and plant N uptake are the critical determinants of survivability in Fig propagation *via* stem cuttings. Data further revealed the presence of strong inter-relationships among these critical traits, thus creating complex trade-offs affecting the overall propagative capacity of Fig stem cuttings. These selected parameters, therefore, could be used successfully as a proxy for determining success in the propagation of Fig through stem cuttings. Using our approach would help in developing indirect selection criterion determining success rates in propagation *via* stem cuttings.

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